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SHORT COMMUNICATION

Estimation of Grain Yields By Remote Sensing of Crop Senescence Rates*

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Remote sensing of crop yields can produce great societal benefits for the world's community of nations (Idso et al., 1975, 1977a). One of the most promising approaches to be taken in this decade is that of crop spectral reflectance assessment, as by the current system of LANDSAT satellites (Hammond, 1975). To our knowledge, however, no technique relying *solely* on LANDSAT data has been developed to accurately estimate grain crop yields. Thus, we broach the subject of grain yield estimation solely by use of this type of data, developing an approach that may prove suitable if satellite-derived spectral reflectances become available on a more frequent basis than is presently the case.

The central idea around which our new technique is built involves the concept of ageing or senescence. In previous studies of crop albedo variations through the growing season (Idso et al., 1977b, 1978), we noted that wheat-field albedo always decreased from the time of heading until senescence began, after which albedo always increased dramatically as the grain began to ripen. For plots stressed for water, which ultimately produced the lowest grain yields, senescence appeared to be drawn out over a longer period of time than it was for well-watered plots, which produced the highest yields. Thus, we inferred the possibility of another approach to yield prediction: the assessment of senescence rates and their correlation with grain production.

We attempted to verify this hypothesis through daily measurement of crop spectral reflectances with a hand-held radiometer that measured radiances in the same four wavebands as the LANDSAT satellites, whereby we could calculate a vegetation index responsive to senescence.[1] Our experimental design is described by Jackson et al. (1979). Briefly, it consisted of planting equal areas of a 72- ×90-m field of Avondale loam at Phoenix, Arizona, to Produra wheat (*Triticum durum* Desf. var. Produra) at two different seeding rates in November,

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[1]LANDSAT Ground Truth Radiometer Model 100-A, 15° F.O.V. lenses, Exotech Inc., Gaithersburg, MD. Trade names are included for the benefit of the reader, and imply no endorsement or preferential treatment of the products listed by the U. S. Department of Agriculture.

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1976, after which six different irrigation treatments were superimposed upon the two planting rates. The next year the field was planted at one seeding rate to equal areas of Produra wheat, Anza wheat (*Triticum aestivum* L. var. Anza), and Briggs barley (*Hordeum vulgare* L. var. Briggs), after which six different irrigation treatments were again superimposed upon these three crops.

Midway between emergence and heading in both years, daily measurements of crop spectral reflectances were begun. Data were obtained between 0920 and 0940 on all clear days; and reflectances in each waveband were calculated as ratios of reflected to incident light, as determined by frequent measurement of reflected radiation from a horizontal flat-plate barium sulfate reflectance standard. Measurements were continued until all crops completely senesced. Final grain yields were then obtained by hand-harvesting the areas of each plot (14 m^2) regularly viewed by the radiometer.

The vegatation index that we chose to illustrate our senescence rate technique for yield prediction is the Transformed Vegetation Index "Six" (Rouse et al., 1974; Richardson and Wiegand, 1977), which is expressed as

$$\mathrm{TVI6} = \sqrt{\frac{\text{Band } 6 - \text{Band } 5}{\text{Band } 6 + \text{Band } 5} + 0.5}\ , \quad (1)$$

where band 5 represents reflectance in the spectral range 0.6-0.7 μm and band 6 represents reflectance in the range 0.7–0.6 μm. This index was chosen because it is highly indicative of green-leaf area and is thus responsive to the loss of chlorophyll and the browning of the crop that accompany senescence. However, there may be other indices that would be equally suitable.

Figure 1 shows mid- to late-season progressions of TVI6 for a representative set of the 1978 plots of Produra and Anza wheat and Briggs barley. The lines through the data points were drawn by a computer procedure that involved the sliding fit of a third-degree polynomial to nine consecutive data points, a procedure similar to the sliding quadratic described by DuChateau et al. (1972). The slopes of the computer-generated curves were evaluated for each day of the senescence period of the crop. The most negative value obtained was averaged together with the results for the five preceding and five following days to characterize the senescence rate. Final grain yields were then plotted against these senescence rates as shown in Fig. 2.

Our first step in the analysis of these data was to run separate linear regressions on the Produra wheat data for the two different years. Statistical tests of the results showed no significant difference between them [$t=0.662$, $P=0.49$ (Zar, 1974)], so we pooled all of the Produra wheat data and calculated the regression line for the entire Produra wheat population shown in Fig. 2.

Separate linear regressions were run on the Anza wheat ($Y=33.5-28560X$; $r_{Y.X}=0.92$; $s_{Y.X}=39$) and Briggs barley ($Y=270-10070X$; $r_{Y.X}=0.44$; $s_{Y.X}=52$) data sets. Once again, statistical tests ($t=0.87$, $P=0.61$; $t=1.64$, $P=0.89$) showed no significant difference between these results and those for the Produra wheat population. This lack of difference is further demonstrated by calculating the percentage of Anza wheat and Briggs barley data points that fall outside of a $\pm 1\ s_{Y.X}$ band about the Produra wheat

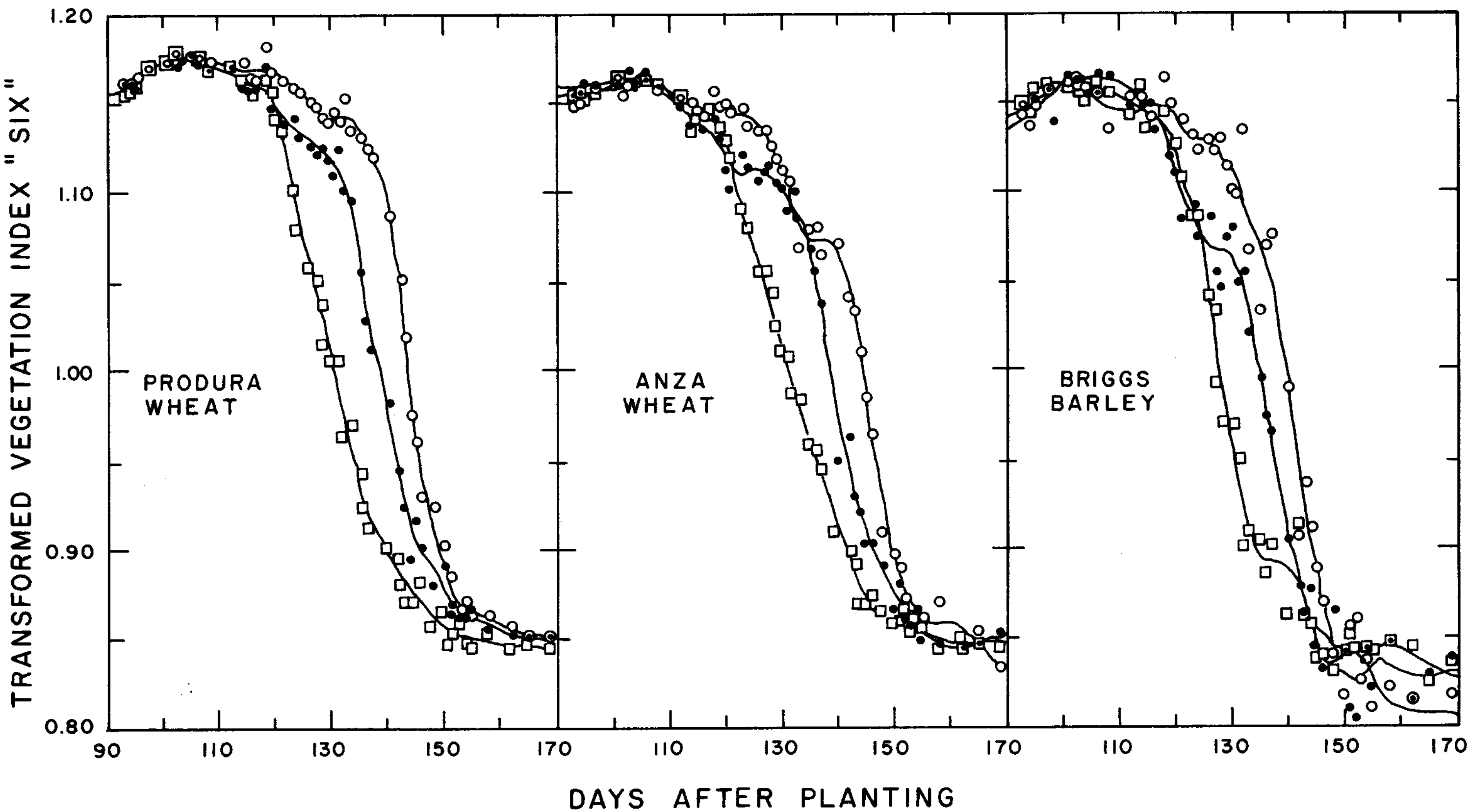

FIGURE 1. Some representative plots of TVI6 versus time for Produra wheat, Anza wheat, and Briggs barley grown at Phoenix, Arizona. High (○), moderate (·), and low (□) water treatments.

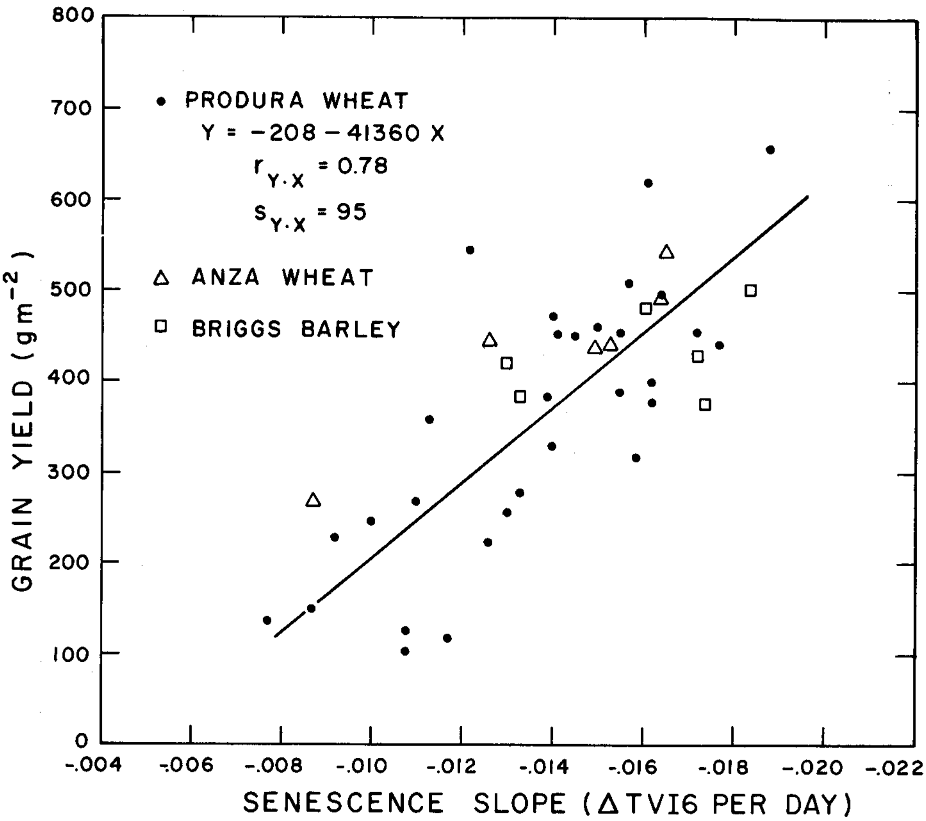

FIGURE 2. Final grain yield of Produra wheat, Anza wheat, and Briggs barley versus senescence rate.

regression line. The result is 25%, exactly the same as for the Produra wheat itself. Thus, it is possible that a single relationship may apply to all three crops, although a much wider yield range of Anza wheat and Briggs barley data is needed to substantiate this hypothesis. Also, our strictly linear relation may not apply to the lower yields that would be obtained with standard dryland farming. Other data are needed to define the relation more precisely as the origin of Fig. 2 is approached.

We conclude from these results that the use of senescence slope determinations to predict grain yields may prove to be a reliable remote sensing technique. Based as it is on the evolutionary strategy for annual plants to prolong their life span when confronted with a stress that could curtail their ability to pass on to the succeeding generation the maximum possible amount of viable genetic material and useful physical resources, the technique is theoretically as well as empirically sound.

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